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LABORATORY NOTES

ON

HEAT MEASUREMENTS

BY

CHARLES L. NORTON

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LABORATORY OF HEAT MEASUREMENTS

The instruction in heat measurement consists of a series of lectures and laboratory exercises which have for their object the training of the student in such methods of heat and temperature measurement as will be of value in later scientific or technical work, and to furnish a foundation for research in thermal lines. Perhaps no portion of the heat measurement field is so fruitful, both to the scientific and to the technical investigator, as is the measurement of high temperatures, or pyrometry. Next in importance comes the measurement of the efficiency of fuels, the determination of their calorific power. To these two subjects the first portion of these laboratory notes is devoted, with the expectation that the additional notes on "thermometry," "thermal conductivity," and "electric-heating apparatus and methods" may soon be added.

All reports handed in must be taken upon the proper blanks and regular physical laboratory paper and should be accompanied by the original records. All reports must be sent in within *two weeks* of the time the observations were finished. When sent back for correction they should be returned with all necessary corrections within *one week*. If not returned to the student within *two weeks* from their first presentation, the experiments may be assumed to need no correction, and they will not be returned to the student until the end of the term.

THE LE CHATELIER THERMO-ELECTRIC PYROMETER

The Le Chatelier thermo-electric pyrometer is based upon the increasing electromotive force which exists at a junction of two metals as the temperature rises. If we have a pair of dissimilar metallic wires, their junction becomes the seat of an electromotive force, and if they be joined at both ends, a current will flow through them as the result of the difference between the electromotive forces at the two ends of the wires. In general, this current is dependent upon the difference in temperature, though not directly proportional to it. In order to use this phenomena as a basis for a pyrometer, since there is no known relation existing directly between temperature and electromotive force in such a circuit, we must expose the junction to known temperatures and note the current flowing, and in this way calibrate. It is usually customary to observe, not the electromotive force, but the current, keeping the total resistance of the circuit constant in order that this may be allowable.

This pyrometer is by far the most important instrument for the measurement of temperature from the point of view of the engineer. It may be found described in detail in Le Chatelier's "High Temperature Measurements," pages 92 to 128 (Burgess translation).

The apparatus consists: first, of a pair of platinum and platinum-iridium wires; second, of a galvanometer; and third, a pair of suitable connecting leads.

Leads. — The lead wires connecting the galvanometer to the junction do not require any special care, other than that necessary to keep them well insulated. These wires should be of some good electric line-wire, not smaller than No. 14, and they should preferably be of the so-called "rubber-covered" type.

Junction. — The junction to be used is composed of one wire of platinum, and one of platinum with ten per cent. of rhodium or iridium. This couple costs nearly ten dollars a foot and must be used with great care. The wires are somewhat brittle, and they are easily attacked when hot by many of the baser metals. The junction in its simplest form is made by merely twisting the wires together at one end and then twisting each to the leads at the other end. It is desirable, however, to be able to know the temperature of the junction of the couple with the copper leads, and it is therefore best to inclose the joints in some receptacle in which a thermometer bulb can be inserted. For laboratory work, a

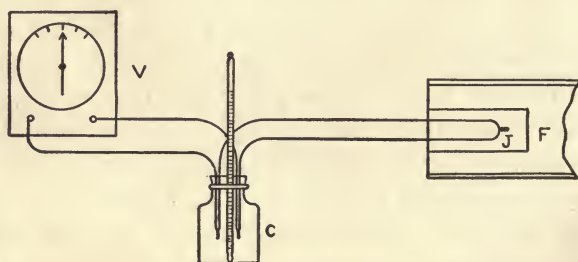


FIG. 1. — Diagram of Thermal Couple.

small bottle with a stopper perforated for the leads and thermometer serves to keep the junction at a fairly even temperature. Where greater constancy of temperature is needed the bottle may be wrapped with some insulating material, felt, magnesia, or asbestos. It is sometimes necessary to put the "cold junction," as the copper-platinum end of the couple is called, in a large block of iron to insure its changing temperature only at a very gradual rate.

The couple must be insulated from itself and from surrounding conductors throughout its length. The best insulation for the cool portions of the wires is a fine rubber tube, while the hotter portions may be insulated with asbestos string wound over and under, in figure-eight fashion, or they may be protected by means of small clay stems with a double bore.

To insure a constant resistance of the couple and leads it is, in all cases, best to solder the cold junction with ordinary soft solder. Resin, and *not acid*, should be used in fluxing this joint, or a slight electromotive force will be found to result, giving serious disturbance to the galvanometer readings.

Unless there is a switch on the galvanometer there should be one inserted in the circuit, as it is necessary to open the circuit frequently for the purpose of reading the zero.

Galvanometers. — There are many galvanometers suitable for use with a thermal couple. Directions will be given for the adjustment and operation of those now in use in the Laboratory of Heat Measurements, and since the galvanometers are of the same general class it is probable that no great difficulty will be found in applying them to others. All the galvanometers especially suited for this work are of the D'Arsonval type, of medium sensitiveness. They operate by the change in position of a coil of wire in a magnetic field, as the current in the coil changes in strength. This change in position is noted either by observing the movement of a pointer attached directly to the coil, or by noting the excursion of a beam of light falling upon a small mirror attached to the movable coil. Galvanometers which may be read by a pointer are made by Heraeus, and Hartmann and Braun. The galvanometers of Sullivan and Carpentier are the best of the instruments using a mirror and scale. The more important details of the procedure in setting up each of these instruments are given below.

Carpentier galvanometer. — This instrument is that most commonly adopted for pyrometric determinations. It will be found described in Le Chatelier, pages 108 to 110. To set up the galvanometer one should select a place as free from vibration as possible, and screen it from any but a feeble light. The galvanometer box should be firmly attached to the wall, taking care to see that it is plumb. The small bob inside the box is intended to assist this operation. Next slip the coil over the iron block between the pole pieces, with

its mirror facing in the direction in which the lamp and scale is to be placed. The suspensions consist of short pieces of fine German silver wire with little balls of the same metal wedged on to the ends. The lower end of the upper suspension should first be inserted in its eye at the top of the coil. See that it is slipped well back in the slot. Next hook the upper end of the suspension in the eye in the flat spring near the top of the box. If the suspension is apparently too short loosen the tension of the flat spring by means of the thumb-screw. Next drop the lower suspension into

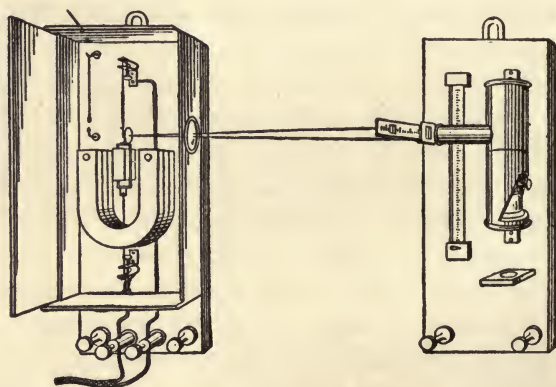


FIG. 2. — Carpentier Galvanometer.

place in the opening between the magnets, and put its two ends in the eyes as before. The mirror may now be made to face in any desired direction by taking the ball at the lower end of the lower suspension between the thumb and finger and twisting it slightly. This is the most troublesome operation of the whole process, and must, moreover, be accompanied with the exercise of great care and patience, or the only result of a great expenditure of time will be a pair of broken suspensions. A small amount of adjustment of the light spot may be gotten later by means of the screw-feet at the bottom of the box.

The lamp and scale should next be set up at a distance of about a meter. It is well to light the lamp and move it back

and forth, and up and down, until it is found that the image is well focussed, and at such a height as makes both the divisions and numbers of the scale visible. When its proper position is found the base-board should be firmly fastened to the wall. It is well to put in a strong screw at the middle of the board near the bottom, in addition to the screw at the top. The oil lamp which is often used where the apparatus is to be carried about, often covers the lens with dew for a few minutes after lighting, and it is well to put off any attempts at focussing until this has disappeared, after the whole lantern becomes warm. As this lamp requires refilling at very short intervals, it should be used only when absolutely necessary. Either a small gas burner or an incandescent lamp should be used whenever possible.

Heraeus galvanometer.—This galvanometer reads by means of a pointer attached directly to the coil. The coil must therefore move through a much larger angle than in the case of the Carpentier instrument with its long beam of light. To make the galvanometer sufficiently sensitive to accomplish this, it has been necessary to use a very fine suspension wire, and to use only the upper suspension. The galvanometer is therefore more frail and must be handled with great care. There are only two adjustments necessary: first, level by means of the screw-feet and the circular level attached to the base; and second, loosen the brass thumb-screw which projects through the side of the brass case. This removes the supporting spring which lifts the coil and takes all strain from the suspension. It is absolutely necessary to screw this thumb-screw firmly in, before attempting to move the galvanometer, otherwise the suspension is quite certain to be broken. There are two scales upon the dial. The outer scale is intended to read in Centigrade degrees directly, with an upper limit of 1600° . The lower scale is in millivolts and it is intended to make the instrument thereby available as a voltmeter as well as a pyrometer. In several of the later galvanometers of this kind there is noticeable considerable "pivot friction," making it necessary to tap the glass of the galvanometer contin-

ually to be sure of freedom from error due to the pivot sticking. None of the joints in these galvanometers in the laboratory were soldered when they were purchased, and their variations in resistance made it necessary to solder most of them.

Sullivan galvanometer.—This galvanometer is similar in many respects to that of Carpentier. It reads by means of a mirror and has an upper and lower suspension. It is, however, more sensitive and it is so free from disturbance from jarring that it may be satisfactorily used on an ordinary laboratory table. Further, the suspension is stout enough to allow the galvanometer to be readily handled and shipped without any unusual care. As set up in the laboratory, it is to be used with a telescope and scale. The scale must first be set up in front of the galvanometer at a distance of about a meter. The telescope should be focussed on the plane mirror and then gradually refocussed until the image of the number on the scale can be clearly seen. Some care is needed in placing the scale and telescope at the proper height, and also in a plane perpendicular to the axis on which the coil turns, so that the image may remain in the field of view as the mirror turns. Care must be used not to disturb the focus of the telescope after calibrating, as the axis of the telescope is not sufficiently constant in position to allow of even slight adjustments, without altering the apparent position of the cross hairs.

Calibration.—Having prepared the junction and having gotten the galvanometer set up and attached to the leads through the switch, the galvanometer may now be calibrated. To do this we observe the deflection of the galvanometer which corresponds to a known difference of temperature at the two ends of the thermal junction. The most convenient temperatures to use are the boiling and melting points given below. The cold junction may be placed in a steam or ice bath, when desired, but it is usually sufficient to allow it to remain at the temperature of the room and read its thermometer at intervals of two to five minutes.

TEMPERATURES FOR CALIBRATION

Substance.	Boiling Point.	Freezing Point.
Water	100.° C.	0°. C.
Naphthaline	218.°	
Sulphur	444.	
Aluminum		657.
Copper		1084.
Gold		1063.
Platinum		1760.

The hot junction should be exposed to these several known temperatures while the deflection of the galvanometer and the temperature of the cold junction are noted, in each instance. A plot should then be made having the deflections as ordinates and the difference between the temperature of the hot and the cold ends of the couple as abscissæ. If the Heraeus galvanometer is to be used with a couple of composition similar to that for which it was originally graduated, it may be well to make the plot as a plot of corrections, having readings of the instrument as abscissæ and corrections as ordinates.

To obtain the galvanometer readings corresponding to the boiling points of water, naphthaline and sulphur, it is best to put the junction directly into a small test tube of the boiling liquid. It makes no difference whether the junction be just above the liquid or well below the surface. Take care not to heat so vigorously as to superheat, or to cause the vapors to catch fire at the mouth of the tube. The highest steady deflection is, of course, the one to be recorded.

To find the deflection corresponding to the freezing points of the metals, we may use either a small bit of the metal wrapped about the hot junction or a larger mass in a crucible. To heat the smaller mass, it is only necessary to use a Bunsen burner for the baser metals and an oxyhydrogen blow-pipe for the platinum. For the larger masses, a crucible furnace, similar to the small Fletcher furnaces in the laboratory, will be needed. The metal should in all cases be heated slowly, and the greatest care should be used to prevent heating more

than a very few degrees above the melting point, as otherwise the platinum and platinum-rhodium will alloy with the melted metal, changing its composition and its freezing point, and the loss of a portion of the junction is also very probable. Especial care is needed when working with hot copper, as the fumes or vapor arising from the melted metal, if it be heated much above its melting point, cause the platinum to be alloyed at a distance of an inch or two from the surface of the hot copper. Since it is difficult to tell from its physical condition, even when large masses are used, at just what temperature a metal melts or freezes, it is best to use the point at which the latent heat of freezing develops as the freezing point. To do this it is only necessary to note the point at which the galvanometer pauses in its swing as the melted metal cools. This momentary pause occurs when the latent heat of freezing develops and prevents for a brief interval the temperature of the mass from passing below the freezing point until all the metal has frozen. To find the platinum point it is best to use a long flame from an oxyhydrogen blow-pipe and draw the junction slowly down through it until the platinum wire melts. With care, a drop of melted platinum may be kept on the tip of the wire for several seconds, and the deflection can be read with a precision quite as good as in the case of the other metals. The eyes must be protected from the intensely bright light of the melted metal by very dark glasses, such as are used in examination of the electric arc. The junction wires may be protected from alloying with metals of low melting points by a fine hard glass tube, but in case this is done, larger masses of metal must be used to insure the junction being at the temperature of the melted metal.

Reports.— Each pair of students will be expected to set up their galvanometer and calibrate it, possibly omitting the platinum point from motives of economy. They will next measure several unknown temperatures, preferably the recalcrescence points of two pieces of steel, and the melting points of several alloys. In case antimony is used it is necessary to perform the melting point determination under the hood.

After having gotten the deflections corresponding to the points sought, they should be looked up in the calibration plot, not forgetting the necessary addition of the cold junction temperature. Bear in mind that the deflection is dependent upon, not the temperature of the hot junction, but the difference in temperature between the hot and cold ends.

PLATINUM RESISTANCE PYROMETER

The platinum resistance pyrometer, or thermometer, of Siemens and Callendar may be found described in Le Chatelier, pages 83 to 91. It is not always given place among the pyrometers, nowadays, because of the great difficulty of keeping the apparatus in proper condition if used at temperatures much above 500°C . Since, however, its precision is very great at low temperatures, and, further, since in the hands of some exceptional observers it has yielded excellent results, it should be classed as one of the most important thermometers.

The operation of the pyrometer is based upon the increase of the electrical resistance of a platinum wire as its temperature rises. After calibration we have only to measure the resistance of the wire in order to determine its temperature. It will be apparent at once that the method is available for use at great distance and under varying conditions of pressure, and in many ways offers advantages over most other methods. Since it is not difficult to measure the resistance of such a coil as may easily be used in this work with a precision of one-twentieth of one per cent., the method takes first place in the ranks of the thermometers in the matter of precision.

The essential parts of the apparatus are, of course, a coil of platinum wire and a bridge with which to measure its resistance. Since the adjustment and subsequent care of a galvanometer and Wheatstone's bridge of the greatest precision would be so great as to call for a considerable outlay of time, it is deemed best to use a less sensitive measuring device and devote more time to studying the method of using and

calibrating the pyrometer. Students will therefore use either the portable testing set or a similar simple bridge with a D'Arsonval galvanometer. The greatest precision sought is a single degree. Be sure and note the number of the coil used.

Connect up the apparatus and measure the resistance of the coil at the room temperature. The blind leads may either be connected in the opposite side of the bridge circuit, or they may be measured separately and subtracted. Of course the object of this is to enable us to measure the resistance of the coil alone without the leads, and it is for that purpose that the blind leads are inserted. They are of the same wire and length as the true leads, and their position beside the true leads assures their being at the same temperature. Find the resistance of the coil in ice, in steam, in boiling sulphur, and in boiling naphthaline. Take great care to keep the tube which protects the coil from too sudden changes in temperature, as its breaking may cause the breaking of the platinum coil, a rather serious matter, as these coils are difficult to wind. Having found the resistances, compute first the "platinum temperature" pt for boiling sulphur. This temperature will be found to be some ten or twenty degrees below the true boiling point as expressed in degrees centigrade (444°). The formula for this deduction is

$$100 \frac{R_t - R_0}{R_{100} - R_0} = pt \text{ (in platinum degrees).}$$

To reduce the pt in platinum degrees to degrees centigrade we must make use of Callendar's second formula, in which t is the temperature in degrees centigrade and pt the platinum temperature as found under the assumption of the equation above, that the increase of resistance is directly proportional to the temperature increase.

$$t - pt = D \left(\left[\frac{t}{100} \right]^2 - \frac{t}{100} \right).$$

In this equation we may substitute the values of pt and t for the sulphur point and solve for D . This need not be rede-

terminated so long as the coil remains free from injury or contamination chemically. Next, with the aid of the first formula, find the platinum temperature of the boiling naphthaline, and then substitute in the second formula, and find the boiling-point in centigrade degrees. The values of t are of course not known in the substitution in the second formula and pt may be substituted instead for a first approximation. A second substitution should then be made with the values thus found. This second approximation will be sufficiently precise. Take care to leave the apparatus in the condition in which it was found, especially taking care to cut off all the gas and electrical supply from the boiling-point cans.

CALORIMETRIC PYROMETER

The calorimetric pyrometer, or, as it is often called, the specific heat pyrometer, of Siemens and Violle may be found described on pages 74 to 82 of Le Chatelier. The measurement of a temperature by the calorimetric method involves the measurement of the heat given out by the pyrometric substance in cooling from the unknown temperature to the temperature of the calorimeter in which it is plunged. If we know the specific heat and weight of the substance, we may compute the temperature, from the total heat received by the calorimeter. Unfortunately the specific heat of such substances as are available for pyrometry varies rapidly with the temperature.

Let W = weight of the substance (platinum or nickel ball).

w = weight of water in the calorimeter.

s = the specific heat of the calorimeter and stirrer.

t_1° = initial temperature of the calorimeter.

t_2° = final temperature of the calorimeter.

T° = unknown temperature to be measured.

s_T = mean specific heat of pyrometric substance (0° to T°).

s_t = specific heat of pyrometric substance (0° to t_2°).

c = weight of the calorimeter and stirrer.

Then when the substance is taken from the furnace, and is plunged into the calorimeter whose temperature thereupon rises from t_1 to t_2 the transfer of heat is shown by the following equation:

$$WT_{s_T} - Ws_t t_2 = (t_2 - t_1)(w + cs)$$

and
$$T_{s_T} = \frac{(t_2 - t_1)(w + cs)}{W} + t_2 s_t.$$

All the terms in the right-hand member of this equation are known after the transfer and subsequent rise of temperature. The term at the left T_{s_T} is the total heat given out by one gram of the substance in cooling from T° to 0° . This quantity has been very carefully determined for platinum and nickel by Violle and others. The values for platinum are given in the table below, for temperatures over a wide range.

T	T_{s_T}
100°	3.23 cal.
200	6.58
300	9.75
400	13.64
500	17.35
600	21.18
700	25.13
800	29.20
900	33.39
1000	37.70
1100	42.13
1200	46.65
1300	51.35
1400	56.14
1500	61.05
1600	66.08
1700	71.23
1800	76.50

Having computed the value of the left-hand member of the equation by substituting the numerical values, the value of T

may be found by interpolating between the values of T_{s_T} in the tables.

Apparatus for temperature measurement in this way is of all degrees of refinement, from an old tin can and a bit of firebrick and an ordinary house thermometer, to the carefully jacketed calorimeter for use with the platinum ball in the laboratory. There is no other method which can be used

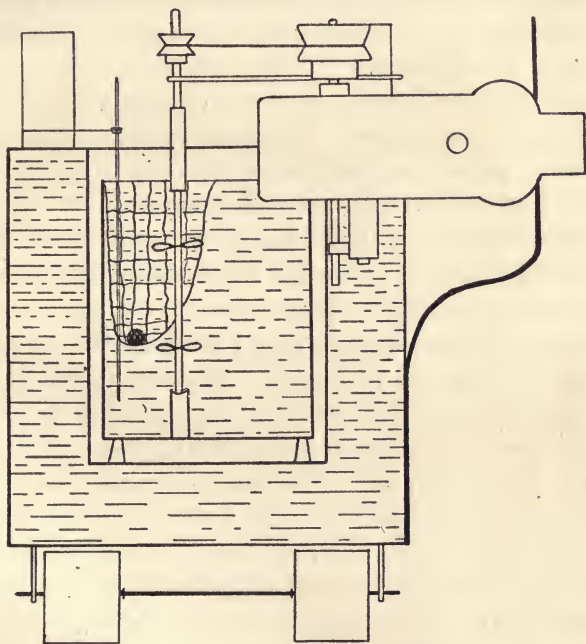


FIG. 3. — Calorimetric Pyrometer.

with so little initial cost, nor so available in regions where little apparatus is to be had. The precautions to be observed are the following:—If iron is used for the ball it must be weighed each time, as the scale which forms is of considerable weight. It is not best to use iron for any but rough work. The water in the calorimeter should be of such amount as to give a rise of temperature of about five degrees, as the calorimeter thermometers are to be read to $1/100^\circ$. The water at the start should be five or six degrees below the temperature of the room. Vigorous stirring is necessary. The

tongs with which the ball is taken from the furnace should be heated to a temperature as near as possible that of the ball, so that the ball may not be unnecessarily cooled on being grasped. Use all possible speed in making the transfer to the calorimeter, as the ball cools very rapidly by radiation in even a very few seconds. A 150-gram ball of nickel or platinum should be allowed to remain in the furnace at least twenty minutes before attempting to use it to measure the temperature, as it is slow in arriving at the exact temperature of the furnace.

Each student will make a measurement with this instrument of the temperature of melting sodium chloride, and such other points as the instructor may call for. The nickel and platinum balls or cylinders are to be returned to the instructor after using. Great care must be taken to avoid contact of the platinum with hot firebrick or other material which would alter its chemical purity. The ball must always be heated on a small platinum tripod or a little pan made of stout platinum foil. In order that the ball may not be further contaminated by alloying with the metal of the calorimeter, a net of platinum wire is suspended in the water of the calorimeter. Failure to properly care for the platinum ball when in use may lead to a very considerable and wholly unnecessary expense. The calorimeter is mounted on wheels, to permit of its being drawn very near the furnace and quickly removed, so that the transfer of the ball may be made rapidly, and yet the calorimeter need be exposed to radiation from the furnace for only a short time.

To measure temperatures of about one thousand degrees with a platinum ball weighing one hundred and twenty-five grams, we need, if we wish to have a temperature rise of five degrees, 500 to 900 grams of water as deduced below.

$$125 \times 37.70 = 5 \times W,$$

$$W = 940 \text{ grams approx.}$$

This, of course, makes no allowance for the weight of the calorimeter, and this need not usually be considered in

estimating the amount of water needed. We may then use from five to nine hundred grams of water, and get a rise in temperature of from five to ten degrees.

The only advantage of using distilled water for this work is that it is possible to keep the calorimeters and thermometers much cleaner when it is used. The apparatus is to be left in the condition in which it was found, with the current for the motor cut off. The thermometers are to be returned to their rack, and, as was earlier noted, the platinum ball is to be returned to the instructor.

LE CHATELIER PHOTOMETRIC PYROMETER

This instrument may be found described in detail in Le Chatelier, pages 144 to 148. It is a portable photometer for the measurement of the intensity of the red light given out by a hot body. When a body is heated it becomes first a dull red, and then a brighter red, then yellow, and finally white. The eye does not indicate that as the temperature rises the intensity of the red increases, because the increase of other colors is greater, but it has been found that the increase of the intensity of the red radiations bears a certain definite relation to the temperature increase. Red is selected because it is present in measurable quantities at lower temperatures. For high temperatures it would be quite possible to use yellow or blue light. By this method, then, we are to measure the temperature by measuring the intensity of the red light given out by the body whose temperature we are seeking. The nature of the surface of the body determines to a considerable extent the amount of light which will be radiated from it when it is raised to a certain temperature, but as this instrument is essentially a secondary one, which must of necessity be calibrated, it is only necessary to calibrate it upon some surface which may be later used as the surface whose brilliancy is measured and under the same conditions as prevail in its later use. A small piece of platinum, or a bit of refractory clay will answer for this purpose.

The photometer itself is of the Cornu type, and it is shown

in plan and perspective in the accompanying cuts. There are two telescopes so arranged that we may see on looking into the common eyepiece, as if side by side, the standard lamp and the object whose temperature is sought. Then by means of the diaphragm in the direct telescope we gradually diminish the apparent brilliancy of the object until it just matches in intensity the standard lamp. The amount of "stopping down" necessary to make the two images match in brilliancy is dependent upon, and a measure of, the temperature of the hot body. In other words, the hotter the

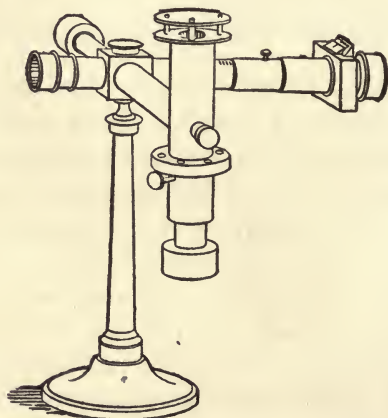


FIG. 4. — Le Chatelier Photometric Pyrometer.

body, the more we must close the diaphragm in order to make the two images appear of the same intensity.

The instrument as shown in perspective in figure 4 and in plan in figure 5 consists of the telescope T_1 with the eyepiece E , the bent telescope T_2 with the mirror M so placed as to bring its objective in line with the eyepiece E ; the standard lamp S , and the "cat's-eye" C . The arm W carries a counterweight to make the apparatus more stable. Usually the standard lamp used for this instrument is a small kerosene lamp. This is a source of great inconvenience, and moreover its variations in brilliancy are considerable. It should be replaced whenever possible by an Argand burner or a large kerosene lamp, having a flame not less than 30

millimeters in height or breadth. This will give a standard which should be constant in intensity within about two per cent. The mirror *M* which deflects the beam of light from the lamp into the eyepiece is of black glass with an exceedingly keen edge, so that the two images may appear to be in close contact with no dark line between. If the mirror should become displaced, so that a dark line appears between the images, the instructor should be called upon to readjust it. The eyepiece *E* needs no adjustment nor any special mention, except that it is liable to become coated with dust

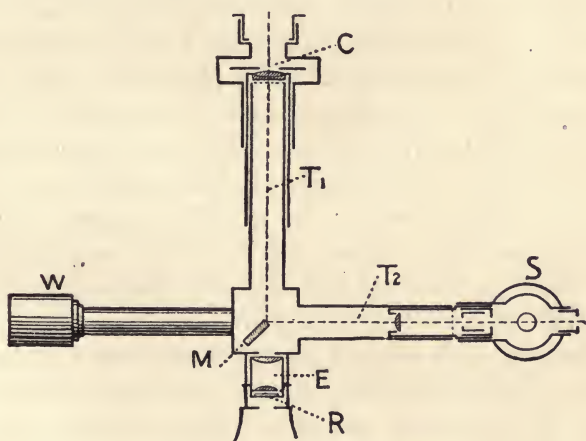


FIG. 5. — Section of Photometer.

and will need frequent cleaning. This applies as well to the objectives. The cat's-eye *C* has a scale attached which indicates the amount of the travel of the diaphragm in closing or opening. It should be in such adjustment as to read zero when the cat's-eye is closed. The telescope *T*₂ needs no focussing but *T*₁ must be carefully focussed upon the object under examination. This is accomplished by sliding the telescope tube in or out after loosening the small set screw on the top. Since there is some uncertainty as to effect upon the intensity, as measured by this particular instrument, of light coming from bodies at different distances, it is best to calibrate the instrument at the same distance as that at which it is to be used.

One or two meters may be selected as a convenient distance for the laboratory.

Having gotten the instrument together, and pointed it at the small furnace which is to be used to heat the calibrating surface, the standard lamp should be lighted and the telescope focussed. This can be best done when the cat's-eye is wide open. If the furnace is not yet red hot, a match flame may be held near the furnace to focus upon. It is well to let the lamp burn for some minutes before beginning the observations, in order that the lamp may become heated and burn at its normal brilliancy. The telescope should next be directed toward the piece of platinum in the furnace which is to be used to calibrate with. This platinum is carried on the end of a thermal couple, and this is connected to the cold junction and the galvanometer. The readings of the galvanometer and the cold junction, together with the correction plot of the galvanometer, will give the temperature of the platinum from time to time. If the Heraeus galvanometer, with the legend "Kaiser and Schmidt, Berlin," on the dial is used, it should be tapped lightly with the finger or lead pencil before each reading to eliminate errors due to pivot friction. The temperature of the platinum in the furnace should now be carried through as wide a range of temperature as possible, temperatures from 650°C. to 1500°C. being easily maintained for a sufficient length of time to make an observation. Reading of the photometer should be taken at intervals of about 100 degrees. At least three runs throughout the entire range should be made. Since there is but one standard lamp provided, and we wish to measure temperatures through a considerable range, we must have some means of making the standard of greater or less brilliancy according to the temperature range in which the temperature we are measuring lies. We do this by inserting either between the standard and the eyepiece, or between the hot body and the eyepiece, an absorbing glass of a grayish or smoky color. This alters the apparent intensity of the object or the standard in a certain definite proportion. The



amount of the absorption is to be obtained by taking readings at some fixed temperature both with and without the smoked glass. This absorption factor should be determined with the greatest care. All of the pieces of glass are from the same sheet and have the same absorption factor, so that only one piece need be examined.

No determination of the absorption factor need be made if we wish to use the instrument over only such ranges of temperature as those at which we may calibrate; but for higher temperatures we must add absorbing glasses and correct the apparent intensities for the amount absorbed by the glasses. For instance, suppose we have calibrated and gotten a plot of the relation of temperature to readings of the scale of the instrument, or rather the squares of the readings. It will be noticed that the scale indicates the amount of linear movement of the parts of the diaphragm, and the square of the readings would indicate the relative area of the opening from time to time; hence it is better to plot the squares of the readings rather than the readings themselves. Let us then take an observation of the temperature of the filament of one of the large incandescent lamps used to light the room. It will be found necessary to insert two or three absorbing glasses, in order to have a scale reading as large as five divisions, which is the smallest reading which should ever be used, as the precision of smaller reading is very poor. Having gotten the reading with three glass, for instance, if we have only calibrated with one glass and without a glass, we must reduce our reading by extrapolating, and should have to assume that the relation between temperature and intensity of radiation remains the same at higher temperatures. For further discussion of this the student is referred to Le Chatelier, with the suggestion that until further data can be gotten, it is well to use the instrument for only such ranges as can be covered by a calibration. As an indicator of changes in temperature it is, of course, available over a larger range.

Each student, after calibrating and getting the necessary data for a plot of squared readings and temperatures, will make determinations of the melting point of copper and of

one other substance, as directed by the instructor. To do this it is best to put one of the small Fletcher crucible furnaces on the floor and point the photometer down into it. The point where the copper melts can be readily noted as the particles of oxide and slag begin to float about on the melting metal. Since all substances radiate at the same temperature with the same intensity, if only they be enclosed in a receptacle at the same temperature, we may use the surface of the copper and need not put the piece of platinum into the furnace near the crucible. If, however, the hot body is not in a receptacle at approximately its own temperature, the platinum must be used.

The report should include data for the plot, the plot, and the temperatures of the melting points as deduced from the plot.

MESURÉ AND NOUÉL POLARISCOPE

The change in the color of the light coming from a hot body as its temperature changes, is the phenomenon upon which the pyrometer of Mesuré and Nouél is based. The instrument is described in detail in Le Chatelier, page 158. It is essentially a pyroscope rather than a pyrometer, being useful for the determinations of slight variations in

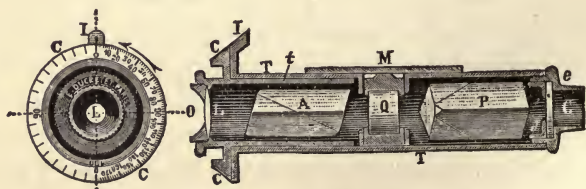


FIG. 6. — Mesuré and Nouél Polariscope.

temperature rather than for the exact measurement of the temperature itself. When a body is heated it becomes first red, then yellow, and finally white hot. In other words, the percentage of red light is greater at the lower temperatures and less as the temperature rises. The polariscope, consisting of two Nicols prisms with a quarter wave plate between them, serves to determine, at least ap-

proximately, the percentage of red in the light from the body under examination. The relative position of the two Nicols necessary to so alter the light passing through them as to make it of any particular color is different with lights of different color, and hence for light from bodies at different temperature. For instance, with a red quarter wave plate we find it necessary to rotate the polarizer more to cause the red to disappear from the field if the light comes from a very hot body than if it comes from one at a dull red heat. And this is exactly what we do in using this instrument. If it be pointed at a hot body, the field is seen illuminated by a red or a green light. By turning the polarizer, the field may be made either red or green as we like, but it will be found that the grayish color or "sensitive tint" which covers the field when it is just passing from red to green, or from green to red, occurs at a particular angle for each particular temperature of the hot body. It is necessary, therefore, to note the different angles at which the sensitive tint occurs with light from sources at known temperatures, and then make a calibration plot. On this plot temperatures may then be found to correspond with readings of unknown temperatures.

Considerable difficulty will be found at first in making check readings with the polariscope, but patience and perseverance will enable one to make fair settings after fifteen or twenty minutes. If one is color-blind in even the slightest degree it is impossible to use the instrument, with hope of success, and students whose eyesight is defective in this way are requested to notify the instructor, who will excuse them from working with this pyrometer.

Each student will make a partial calibration of the polariscope and measure several unknown temperatures. The calibration is to be made as in the case of the Le Chatelier photometric pyrometer with the aid of a bit of platinum and the thermo-electric pyrometer. The temperatures to be measured will be indicated by the instructor, if possible the ordinary working temperatures of the small muffles and pot furnaces in the mining laboratory should be among them.

MEASUREMENT OF HEAT OF COMBUSTION

There are three methods of so burning a fuel as to measure its heat of combustion or calorific power: first, by igniting it in a stream of oxygen; second, by confining it in a strong receptacle with sufficient oxygen to completely burn it; and third, to mix with it, before ignition, some solid which will furnish oxygen when heated. The first method gives us the calorimeters of William Thomson and George Barrus; the second, the bomb calorimeter of Berthelot, Mahler, and Norton; and the third, the calorimeter of Parr using sodium peroxide as an oxidizing substance, and that of Stohman and Lewis Thomson using chlorate and nitrate of potassium or peroxide of manganese.

Of the several pieces of apparatus available for the measurement of heat of combustion, all make use of a calorimeter in which to measure the heat directly. The Junkers calorimeter, for the measurement of the heat of combustion of gaseous and liquid fuels, is a "continuous" calorimeter, the others are of the familiar "method of mixtures" type. Of the three methods, that making use of the bomb is most precise, that of Professor Parr is the most convenient and most readily adaptable to the needs of engineering practice, while the Junkers apparatus is far better for the measurement of the efficiency of gaseous fuels than any of the others.

Coal.

The coal from which the sample is taken should be free from large lumps; such lumps can be broken up with a hammer.

After thoroughly mixing the sample, spread it out on a piece of glazed paper, and take a "grab" or hand sample, here and there, until about 75 grams are obtained. If the coal is already finely ground, 50 grams will suffice.

Grind this quantity in the small iron mortar until it will pass the 100-mesh sieve. Pass the entire amount through the screen, as otherwise it will have an undue proportion of

the softer materials and will not be a representative sample. Pour the screened coal on to glazed paper, and, after thoroughly mixing, spread it in an even layer and sample with a spatula, taking enough to nearly fill a wide-mouth sample tube. Place this in the drying closet at 110°C . and leave there for fifteen minutes. This heating is for the purpose of driving out the moisture so that water will not be weighed as coal.

Weighing.

The balance used is sensitive to $\frac{1}{10}$ milligram and is therefore delicate and *must* be handled carefully.

The arm is lowered on to its knife-edge by turning the large knob to the left, and care must be taken not to do this until approximately equivalent weights are in the pans.

Whenever the substance is removed from the left-hand pan or the large weights are changed, the balance arm *must* be raised on its supports. Failure to do this may throw the balance out of adjustment and permanently injure it.

Fill a small weighing tube two-thirds full of the dry coal and place it on the left-hand pan of the balance. Weigh the tube and coal to the nearest milligram, *i. e.*, the largest division on the arm of the balance.

After the weight has been ascertained, raise the balance arm on its supports and remove weights, corresponding to the weight of coal desired, from the pan.

Pour out enough coal, a little at a time, to counterbalance this change in weights until within the allowable error of one milligram.

Always record the different weights of the tube and coal, so that the last weighing of one sample may be used as the first weighing of another, provided that no coal has been spilled in the meantime.

In this way several successive weighings can be made with rapidity and precision. The weights must be returned to their proper places, the balance arm raised, and the slide closed after *every* weighing.

FUEL COMBUSTION BOMB

The method of measuring the heat of combustion of fuels by burning them in a bomb with oxygen at high pressure is due to Berthelot, and apparatus has been devised for working according to this method by many experimenters. Perhaps the best known bombs are those of Mahler, Donkin, Atwater and Hempel. The one used in the Laboratory of Heat Measurements is the result of the joint efforts of several members of the instructing staff of the Institute. It differs from earlier bombs in material and design, and the result of six years' use in the hands of a large number of students shows it to be a durable as well as a practical type of instrument. It is made of aluminum-bronze, having a composition of ninety parts of copper to ten parts of aluminum. The object of the use of this particular alloy is to avoid the lining with platinum or enamel, which has been one of the most troublesome features of many types of bomb. This alloy is nearly or quite as strong as steel and is not attacked by the oxygen under the ordinary conditions of use. The object of having the joint in the centre of the bomb is to insure ease of access to all parts of the inner surface for cleaning. The joint is merely an enlarged plumbers' union, and it is essential that it should be *freely lubricated upon the shoulder upon which the nut bears, but that it should be scrupulously clean on the bearing surface of the lead packing ring*. The greatest care is needed to keep the two faces of the upper and lower hemispheres free from scratches and dents, since otherwise it will be impossible to make the joint tight. The valve is essentially a delicate piece of mechanism and it must not be strained.

The directions for using the apparatus are given somewhat briefly below.

The Bomb.

Remove the calorimeter from the jacket and put into it 2,000 c. c. of water at a temperature of about 4° below that of the room.

Open the bomb and put the pan in place; cut off about

two inches of the platinum fuse wire and connect it so that it passes from the insulated eye in the bomb, through the hole in the upright piece on the pan, and across to the other side of the pan. (See Fig. 7.) Be sure that the wire dips well down into the pan, but does not touch the bottom. Now test the fuse wire by touching one lead wire of the igniting circuit to the insulated plug on the outside of the bomb, and the other to the bomb itself. If the platinum wire flashes red, the connections are properly made.

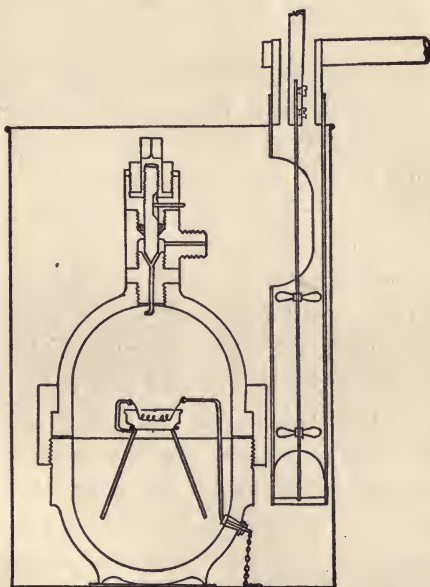


FIG. 7. — Combustion Bomb.

Weigh one gram of coal directly into the pan, and put the pan in position in the bomb. Having the coal and fuse in place, clamp the lower part of the bomb tightly in the socket provided for it.

See that the screw and nut are scrupulously clean and well oiled. Do not put oil on the lead packing ring, and see that it also is clean. Put on the top half of the bomb, slip the nut down over it, and see if it fits easily and turns smoothly. If it does not, call the instructor.

The bomb must be closed with a strong, steady pull, not a hard jerk. Keep one foot well out to the rear, to guard against the consequences of a slip of the wrench. Having tightened the joint, let it stand for three or four minutes, and tighten again to take up any looseness due to the flowing of the lead packing.

Connect the copper tube of the oxygen supply with the nipple at the top of the bomb, leaving the bomb valve open; turn the screw to the right to open the valve, which is "left-handed," and be careful not to strain this valve, as it has a very fine thread.

Let the oxygen in *slowly* until the gauge shows a pressure of 300 pounds. Close both valves tightly and uncouple the tube from the bomb. Now put the bomb into the calorimeter, first hooking one of the lead wires into the ring in the side plug of the bomb. Be careful not to touch the other lead wire to the bomb while the switch is closed, and thus prematurely fire the charge, and also not to move the bomb violently enough to spill the coal out of the pan.

Put the calorimeter into the water jacket and the bomb into the water; start the stirrer and run five minutes before the temperatures are read, as the bomb is probably not at the temperature of the water when it is first immersed.

Insert the thermometer and read every half minute for fifteen minutes. At the end of the first five minutes, ask instructor to ignite the charge. The temperature should rise rapidly, reaching a maximum in about two and one-half minutes, and then fall slightly till the last reading is made. Then stop the motor, remove the bomb from the water and put back in the clamp.

Open the valve to let the products of combustion escape, and then open the bomb.

Wash out the pan and bomb and leave them *clean* and *dry*.

The specific heat of the bomb is $.093^{\circ}$; that of the can and stirrer is $.095$.

The can and bomb can be weighed on the platform scales. The weight of the stirrer is 100 grams.

The cooling correction is to be computed and allowed for as directed in the third year laboratory notes on heat.

Each student will make an examination of two fuels, making two combustions on each. The report should give the calorific power in calories per gram and B. T. U. per pound of fuel. Students must not fire the charges until instructed specifically to do so, as carelessness may result in a serious explosion.

PARR CALORIMETER

The calorimeter for the measurement of heat of combustion in which the oxygen is supplied from the decomposition of sodium peroxide is due to Professor Parr and bears his name. The essential parts of the apparatus, as shown in Fig. 8, are the combustion chamber, the calorimeter and water jacket, and a small motor to furnish power for stirring. As originally planned, the ignition was to be brought about by dropping a hot wire through an opening in the top of the combustion chamber. This was covered by a valve which closed with a spring when the bit of hot wire had been dropped in. Because of a serious accident resulting from the failure of the valve to close, with consequent discharge of the hot contents of the combustion chamber upon the hands and faces of the observers, an electric ignitor has been inserted.

Setting up of the Instrument.

The calorimeter should be placed on a firm desk or table and accessible to motive power which may come from a small electric motor, water motor or line shafting. The power needed is exceedingly slight, the smallest electric or water motor being ample. The speed when transmitted to the instrument should not be too high; 50 to 100 revolutions of the pulley attached to the calorimeter is sufficient.

The small rubber collar is to be slipped on the stem of the thermometer, for supporting it when passed through the lid of the calorimeter. It should be so placed as to bring the bulb of the thermometer about half way down from the top of the can. While other preparations are progressing,

hang the thermometer near the calorimeter, in order to ascertain the temperature of the room.

Fill the two-liter flask to the mark with water about 4° below the room temperature. The calorimeter should be removed from the instrument for filling. Inside of the calorimeter should be placed the deflecting collar and pivot. The combustion chamber should be *perfectly dry* inside and out.

To prepare the combustion chamber for filling, screw on the bottom firmly, so as to avoid any possibility of admitting

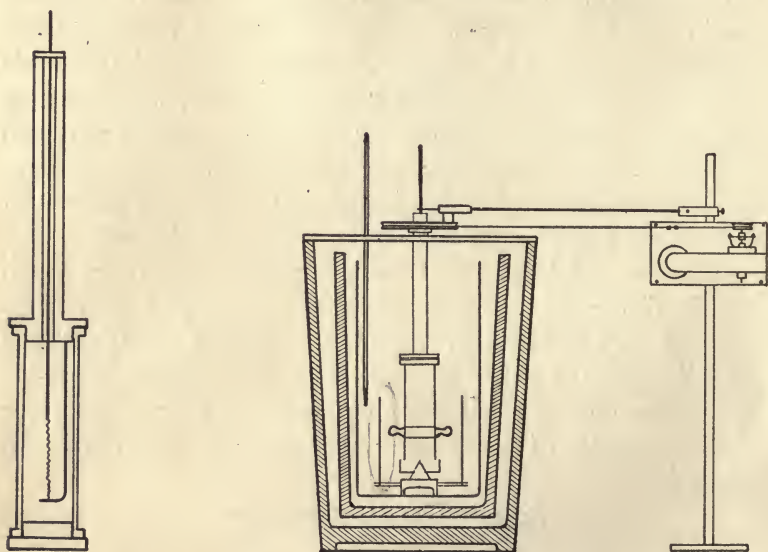


FIG. 8. — Parr Fuel Calorimeter.

water to the interior, then place it on a sheet of white paper.

The sodium peroxide and the small measuring cup are to be kept in a glass jar, which must be kept closed. The sodium peroxide must not be scattered about, and care should be taken not to get it upon the clothes or hands. Keep everything with which the sodium peroxide comes in contact perfectly dry.

The directions for manipulation follow. After the final reading in a test has been taken, dismantle by first carefully removing and hanging up the thermometer. After removing

the pulley and cover, take out the calorimeter entire, then remove the cartridge from the water, remove the spring clips with vanes, unscrew the ends, clean them at once with a dry towel, and place the cartridge under the tap or in a basin of water. The contents should dissolve out rapidly and in a few minutes the cartridge will be ready for rinsing and drying. Dissolving the contents of the cartridge in a basin has the advantage of indicating whether the combustion is perfect or not. Of course precipitated iron and ash will always be in evidence. The result is still better shown by acidifying with commercial hydrochloric acid, when practically a clear solution should result.

Manipulation.

The coal, properly sampled, should be ground in a mortar and passed through a 100-mesh sieve. The amount so treated need not be large, an ounce or less being sufficient. Upon a carefully counterpoised watch-glass weigh exactly one-half gram and place in the oven to dry. The oven should be maintained at 105° to 110° C. The coal will be sufficiently dry in fifteen minutes, having been dried previously. If, however, an accurate determination of the water is desired, it should remain in the oven at the above temperature for one hour and cooled in a desiccator or in ground-clamped watch-glasses before weighing the second time. For the calorific test the determination of the water is not necessary, hence, after fifteen minutes in the oven at the proper temperature, the sample is ready. Students need not take time for this. To the half gram of coal, when cooled to about the temperature of the hand, add in the watch-glass or upon a piece of glazed paper, one measure—the small dipper-like measure in the glass jar—of sodium peroxide. Mix thoroughly and carefully with a knife or spatula. Do *not* grind the mixture, but turn it and stir it, and be as quick as possible. Put the entire mixture into the combustion chamber. See that the bottom is screwed on firmly before filling, and put the fine platinum fuse in place between the

brass posts on the under side of the cover. It is well to put the chamber on a piece of blue glazed paper so that particles which are spilled may readily be collected.

The measure is adjusted to hold very nearly $8\frac{1}{2}$ or 9 grams of sodium peroxide when tapped to settle the contents, and at the same time shake off the excess at the top so that it will conform somewhat to a "struck" measure. Extreme accuracy in this regard is not essential. Be sure, however, that the measure has been filled to the exclusion of large cavities that may tend to form. Return the measure to the glass jar *at once*, and keep the whole covered and clamped to exclude moisture.

When the mixing is complete, tap the cartridge lightly on the bottom to settle the contents and to shake all the material from the upper part of the cylinder. Put on the spring clips with vanes. The cartridge is now ready for inserting in the calorimeter. The calorimeter is made ready by standing it outside the apparatus and adding thereto 2,000 cubic centimeters of distilled water which has been previously brought to a temperature a little below that of the room, — say about 4°C . This adjustment of the temperature of the water should be made while it is yet in the two-liter flask. If too warm, allow the tap water to flow over the flask. If too cold, pour a little into a beaker and heat over a Bunsen burner, or better still, if available, hold the flask under a hot water faucet. Mix the water in the flask before thus roughly taking the temperature. Since the average coal gives a total rise of about 3°C . for $\frac{1}{2}$ gram, it is a simple matter to know approximately what the initial temperature of the water should be. It is well to make a note of the temperature of the room in the data of the experiment.

Pour the water into the calorimeter and lift the same into the jacket. The pouring in of the water should be made with the calorimeter removed, to avoid getting any moisture on the outside of the calorimeter or in the air spaces. Now insert the combustion chamber, adjust the cover, place the thermometer so the bulb will extend about half way to the bottom of the calorimeter, place the pulley on the stem,

adjust the arm carrying the igniting brushes, and connect with the motor. The general arrangement of parts is shown in Fig. 7. Too rapid revolving of the cartridge should be avoided, 50 to 100 revolutions per minute being sufficient. The cartridge should turn to the right, or as the hands of a watch, thus deflecting the water currents downward. Read the thermometer carefully every fifteen seconds. After five minutes ignite the charge by closing the switch. The combustion should be indicated by a rapid rise of the mercury, which reaches its maximum height after about five minutes. Read the thermometer every fifteen seconds to the nearest 10° until ten minutes after it starts to rise. Make note of the final maximum temperature and compute as follows: The cooling connection should be made as indicated in the Laboratory Notes on Heat in use in the third-year laboratory, and if it is so small as to be negligible, it should be so stated in the report.

The difference is the actual rise " r " due to the total reaction inside of the cartridge. Multiply " r " by the factor 3,100 and the product equals the calories per gram of coal.

Notes. — (a) The factor 3,100 is deduced as follows; The water used plus the water equivalent of the metal in the instrument amounts to 2,123 grams. In the reaction, 73 per cent. of the heat is due to combustion of the coal, and 27 per cent. is due to the heat of combination of CO_2 and HO_2 with the sodium peroxide and monoxide.

If now $\frac{1}{2}$ gram of coal causes 2,123 grams of water to rise " r " degrees, and if only 73 per cent. of this is due to combustion, then —

$.73 \times 2123 \times 2 \times "r" = \text{heat that results from the combustion of one gram of coal. } 2 = 3100.00 \times "r."$

Give the calorific power in B. T. U. per pound as well as in calories per gram.

(b) The moisture in "air dry" coal may vary from one to fifteen or more per cent. When this quantity does not exceed two or three per cent., the error introduced in the reaction by not removing it would be too small to be of tech-

nical consequence. It is better, however, in all cases to dry the coal as directed.

(c) In the case of coke, drying is usually unnecessary. Ashes, if they have been sprinkled, should of course be dried. Ashes and sometimes coke ignite with difficulty. In such cases add a second charge of sodium peroxide and $\frac{1}{2}$ gram of some good coal, the factor of which has been determined, mix the two charges thoroughly by shaking, and ignite. The coal will carry along the combustion of the entire mass. Calculate the B. T. U. as usual and subtract the B. T. U. due to the coal.

(d) The receptacle for the sodium peroxide is so arranged that, with the contents of one can of sodium peroxide in the bottom, there is still room in the jar for the measure and handle complete. The measure should always be replaced in the jar and the cover clamped on.

(e) Do not spill the sodium peroxide. Do not pour a mixture of the sodium peroxide and coal into water. It may ignite violently. When thrown into wet excelsior or damp organic matter may cause ignition. If much is spilled on the hands wash thoroughly at once. The fine dust that may be breathed into the nostrils is harmless; use care and common sense. There should be no more liability to accident than in the use of any other caustic.

(f) A sample of coal ground finely, even if carefully kept in a corked bottle, slowly deteriorates. An appreciable loss may be noticed after a week. As much as two per cent. deterioration has been noted after six or eight weeks. Lump or pea samples are not thus affected.

JUNKERS GAS CALORIMETER

Principle The Junkers calorimeter is available for the measurement of the heat of combustion, or calorific power of gas, kerosene, and gasoline. The apparatus is illustrated in the accompanying cuts. The calorimeter is of the "continuous" type. It is essentially a small tubular boiler in an upright position. The heat developed by the flame under the boiler

raises the temperature of the water as it passes through the apparatus. A measurement of the amount of water passing, and the amount of the temperature rise, gives us at once the heat developed by the flame. This may be expressed in calories, or gram-degree C. units or in British Thermal Units, the pound degree F. unit.

To set up the apparatus it is first necessary to so locate the boiler that it may have a constant supply of water at a nearly constant temperature. If there are great fluctuations

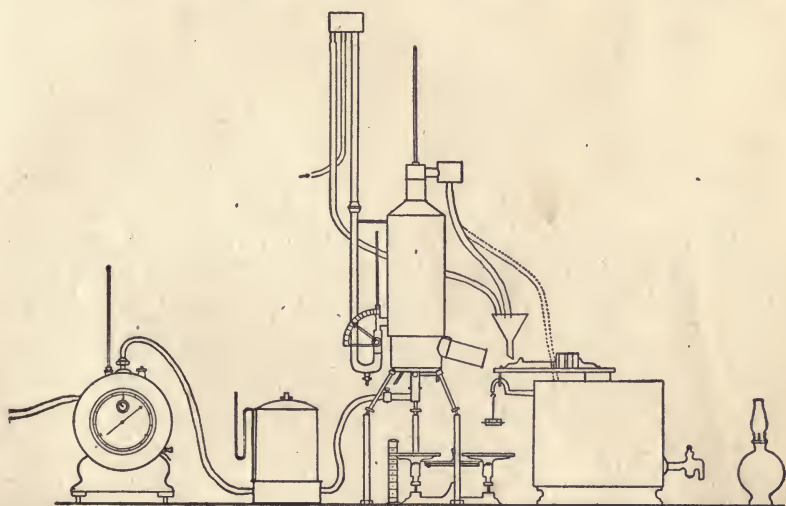


FIG. 9. — Junkers Gas Calorimeter.

of the temperature of the supply mains, a large tank at the top of the room will answer for several determinations. If it can be fitted with a ball cock, as are the common tanks for household hot water supply, it will serve admirably. Beside constant temperature of the water supply one other condition must be maintained, — that of constant "head" or pressure. This is accomplished by means of the small cup, which is to be kept full while the apparatus is being used. The best way to be sure that the cup is full is to keep the overflow pipe dripping slightly. It is well to put this in a conspicuous place so that a stopping of the overflow may be immediately noted and more water supplied to the cup. The outlet pipe should

*Hot
water
supply
T
outlet p*

be provided with a three-way-cock connection, so that the water which has passed through the calorimeter may be run into the tank, to be weighed or measured, or into the drain as desired. It is necessary to so arrange this that the transfer from tank to drain may be made quickly, as we wish to begin the measurement of the water at a definite time with a precision of about one second. The water may be measured in calibrated flasks, but it is much better to weigh it and to use a long run and a large amount of water.

The gas meter for use with this experiment may be assumed to be in proper order without calibration correction. If, for any reason, the meter is jarred or moved, it must be emptied and refilled. The dial reads in liters, being graduated so that one revolution of the long pointer indicates three liters. The small dial has divisions of three liters, making one revolution on the large dial correspond to one division on the smaller dial. The pressure regulator must be put in the pipe from the meter to the calorimeter. It is a floating inverted cup which, as it fills with gas and rises in the water, closes the valve through which it filled and then falls, to be filled again. The pressure of the gas coming from it may be regulated by adjusting weights on the top of the cup, changing its tendency to sink, and the length of time for which the valve remains open. The regulator should be filled with water to a depth of about three inches. If gasoline or oil are to be tested instead of gas, it is, of course, not necessary to use either meter or regulator, but the lamp should be put under the calorimeter on platform scales, and the loss of weight as the lamp burns should be noted and recorded just as are the gas meter readings in the determination under discussion. Having gotten the meter set up, the

regulator filled and in position, the calorimeter filled and the supply cup overflowing, the burner must be removed and lighted and then clamped in position under the central tube of the calorimeter. The temperature of the outlet water should at once rise. Watch it carefully for several minutes to see that it does not go high enough to endanger the thermometer. It should be regulated in height by changing the amount of water entering the apparatus by means of the valve, which, with its dial, affords a very close adjustment. It is well to adjust the supply so as to have the difference between the inlet and outlet temperatures about fifteen degrees. Be careful never to start the fire under the boiler unless you are certain that it has its normal amount of water.

No observation should be taken after the adjustment of the water supply until after an interval of five minutes, in which the whole calorimeter may come to a condition of equilibrium. The necessity of the delay in starting lies in the slowness with which the condensed water begins to drip at a steady rate. Observations taken within five minutes of the readjustment of the gas supply are liable to be in error, because of this slowness or "lag" in the drip, by several per cent. The observations to be taken are the temperature of the inlet and outlet water, the amount of gas or oil, and the weight of water passing per minute. It is well to make a run of eight minutes' duration. The gas meter should be read at the beginning of the run and once each minute during the run, so that the rate of gas supply per minute may be known. The weighing of the water should be begun at a carefully noted time, preferably the time at which the gas meter readings are begun, and ended at the close of the stated eight minutes with a precision of one or two seconds. If, in an eight-minute run, we are in doubt as to the length of time taken by the gas or water which has been measured, in passing through the calorimeter, by an amount as great as two seconds we are in doubt as to the calorific power of the gas by about two parts in 480, or nearly one half of one per cent. This will emphasize the necessity of making a long run. The thermometers may be read at such times as are

convenient without disturbing the gas meter readings, but at intervals not longer than thirty seconds. The drip from the condensed gas is to be collected for the entire run. We should have at the close of the run the following observations:—

- ✓ Table of inlet temperatures (30 seconds).
- ✓ Table of outlet temperatures (30 seconds).
- ✓ Table of gas meter readings (Start, minute intervals to finish).
- ✓ Weight of water passing in entire run.
- ✓ Weight of drip, for entire run.
- ✓ Time of start and finish.

The formula necessary for the reduction of these observations is as follows:—

Let W = grams of water passing per minute.

t = average temperature of inlet water.

T = average temperature of outlet water.

G = liters of gas burned per minute.

d = grams of water condensed per minute.

H = heat of combustion of one liter of gas in calories.

Then:

$$H = \frac{W(T - t) - 537d}{G} \quad \text{net heat}$$

The calorimeter measures directly without allowing for the drip the *total* heat of combustion of the gas, but since few heating devices condense the water in the products of combustion, but allow the water to escape as steam, it is necessary to report for commercial tests, not only upon the total calorific power of the gas, but also upon its calorific power when used in a gas engine or gas heater. To do this it is necessary to collect the drip and to subtract its latent heat of condensation from the total heat as measured by the calorimeter. Since the latent heat developed by one gram of water in condensing is 537 calories, it is necessary to multiply the weight in grams by 537, as indicated by the last term of the equation above.

Report. — Each pair of students will make three determinations of the calorific power of the Boston city gas. Use slightly different rates of gas by changing weights on pressure gauge. Make also a duplicate set of determinations of the calorific power of kerosene, burnt in an ordinary lamp and in a blue-flame lamp, and of gasoline in the Barthel lamp. Report on the gas in calories per litre and also in B. T. U. per cubic foot. The liquid fuels are to be reported in calories per gram and B. T. U. per pound. Leave the apparatus with both water and gas supply cut off, and the oil and gasoline burners returned to their proper places.





























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